Chemie der Erde 76 (2016) 111–116

Contents lists available at ScienceDirect

Chemie der Erde

journal homepage: www.elsevier.de/chemer

Petrography and classification of NWA 7402: A new sulfide-rich unequilibrated ordinary chondrite

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ARTICLE INFO

Article history:
Received 26 January 2015
Received in revised form 1 September 2015
Accepted 4 January 2016
Editorial handling - K. Keil

Keywords:
Meteorite classification
Unequilibrated ordinary chondrites
Meteoritics
Cosmochemistry
Early solar system
Petrography

ABSTRACT

We classify a new chondritic find Northwest Africa (NWA) 7402. This meteorite is highly unequilibrated, and is therefore potentially significant for the study of primitive Solar System materials. Mineralogy, mineral chemistry, and modal abundances of minerals indicate that NWA 7402 is most likely an L chondrite. However, the specimen contains a higher abundance of sulfide than commonly seen in ordinary chondrites. The structural order of organic matter in the matrix and the chromium content of Fe-rich olivine grains indicate a petrologic type of 3.1. NWA 7402 largely escaped thermal metamorphism, and secondary phases formed by aqueous alteration are rare to absent. Minor planar fractures and undulatory extinction of olivine grains suggest that NWA 7402 experienced shock up to stage 2 or 3. Terrestrial weathering is heterogeneous in the specimen; much of the stone's exterior shows substantial Fe oxidation (weathering grade 2), while some parts of the interior remain relatively fresh (weathering grade 1). NWA 7402 has some unusual features that should be investigated further. The sulfide abundance is higher than reported sulfide contents for other L chondrites, and the chromium content of the olivines does not fall on the trend established for unequilibrated ordinary chondrites by Grossman and Brearley (2005).

1. Introduction

A new chondritic meteorite find Northwest Africa (NWA) 7402 displays rare features suggesting that it could be highly primitive, warranting detailed study for classification purposes. NWA 7402 is a 4013.4 g individual stone, purchased on August 26, 2010 by Eric Twelker of the Meteorite Market from a meteorite trader in Morocco (Fig. 1). Its history – including finder and location – remain unknown, as is the case with many NWA meteorites. Samples of NWA 7402 were supplied to the University of Hawai'i at Mānoa for classification purposes, and a mass of 25.5 g was sent to the University of New Mexico repository as the type sample. We have employed optical microscopy, scanning electron microscopy (SEM), electron microprobe analysis (EPMA), and Raman spectroscopy to determine the chemical group, petrologic type, stage of shock, and terrestrial weathering grade. During the classification process, some unusual features were noted that potentially deserve further study.

2. Analytical techniques

Primary petrographic characterization of NWA 7402 was conducted with optical microscopy. To evaluate terrestrial weathering, the degree of oxidation of metal grains was assessed, following Wlotzka (1993). The modal abundances of Fe-bearing phases (metal, sulfides, and weathering products) were determined by point counting using the reflected-light method of Boeck et al. (2009). The optical microscopy methods and criteria proposed by Stöffler et al. (1991) were used to assess the degree of shock in NWA 7402.

The thin and thick sections were subsequently carbon-coated for the SEM and EPMA. Qualitative mineral identification was done with energy-dispersive X-ray spectroscopy (EDS) on the SEM. The modal abundance of components (including chondrules, fine-grained matrix and rims, opaque assemblages, and isolated silicate grains) were counted in the NWA 7402 thick section using a grid and a backscattered electron (BSE) map of dimensions 3 mm × 2.5 mm.

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http://dx.doi.org/10.1016/j.chemer.2016.01.001
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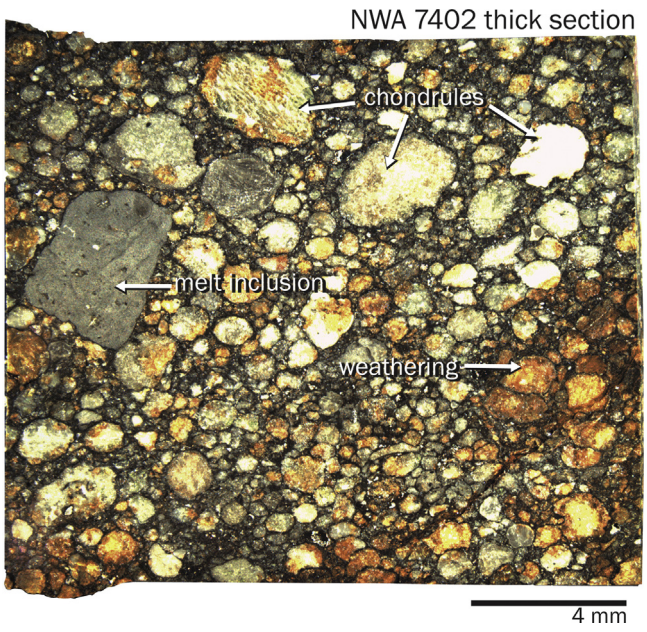

Fig. 1. Optical image of the NWA 7402 thick section. Chondrules vary in size from <200 μm to >3 mm. Heterogeneous terrestrial weathering is apparent as rust-colored regions in the sample.

Multi-element X-ray maps were taken using the JEOL Hyperprobe JXA-8500F Electron Microprobe at the University of Hawaii. X-ray maps were taken at 20 keV, 50 nA with a 5 μm beam diameter, and 25 ms dwell time.

Quantitative elemental analyses were conducted with EPMA to determine the chondrite group for NWA 7402, using the methods of Van Schmus and Wood (1967). Over the course of two sessions, a total of 261 chondrule silicates were chosen at random and measured for Al, Ti, Na, Fe, K, Si, Cr, Mg, Mn, and Ca. Standards included San Carlos olivine, sphene glass, Amelia albite, orthoclase, Verma garnet, and USNM 117075 chromite. The Fe contents of the silicates are also reported in terms of the fayalite (Fa) content for olivine and the ferrosilite (Fs) content for pyroxene, expressed in mol%.

The Cr_2O_3 contents of Fe-bearing olivines were used to determine the petrologic type, following Grossman and Brearley (2005). Of the NWA 7402 olivine grains measured by EPMA, 140 had FeO > 2 wt%, suitable for petrologic-type determination. To assess the accuracy of the analyses, 56 chondrule olivine grains in Semarkona (LL3.00) and 43 in Bishunpur (LL3.15) were also measured for Cr_2O_3 under the same analytical setup. The measurement points were selected from regions not visibly affected by the fusion crust, as entry heating could have altered the Cr_2O_3 composition of exposed olivine.

To further constrain petrologic type, Raman spectroscopy measurements were conducted at Laboratoire de Géologie de Lyon (Université Claude Bernard – Ecole Normale Supérieure de Lyon, France). Following Quirico et al. (2003) and Bonal et al. (2006, 2007), matrix material was separated (<50 mg) and measured via Raman spectroscopy. For type 3 chondrites, the most sensitive spectral parameters to thermal metamorphism are the width and intensities of the so-called D and G bands. Spectral parameters for the D and G bands were fit with Lorentzian and Breit–Wigner Fano mathematical profiles, respectively. Petrologic type can be assigned by comparing these parameters to those of reference samples.

3. Results

3.1. Petrographic observations of NWA 7402

NWA 7402 is a chondritic breccia, with occasional lithic clasts of impact melt present (Fig. 1). Rust-colored, apparently weathered areas with orange-brown chondrules surround less-weathered regions containing light yellow-gray chondrules set within a darker gray groundmass (Fig. 1). The less-altered regions on the interior of the meteorite show minor oxide veins (Fig. 2) and alteration of Fe-rich phases, consistent with weathering classification of W1 (Wlotzka, 1993). However, the more weathered portions show at least moderate oxidation of metal with about 20–60% being affected, consistent with a W2 grade (Wlotzka, 1993).

The meteorite contains a high abundance of chondrules embedded in a clastic, sulfide-rich matrix (Figs. 1 and 2). Opaque assemblages composed of metal, Ni-poor sulfide (either as troilite or pyrrhotite), and magnetite are common. Apparent chondrule diameters range from ~0.2 to 3 mm; this distribution may differ from the true sizes due to sectioning effects (Hughes, 1978; Eisenhour, 1996). A melt inclusion of approximately 4 mm in length is present in the thick section (Fig. 1), and an anomalously large barred-olivine chondrule of 8 mm in diameter exists in one thin section. Chondrule types include porphyritic olivine and/or pyroxene, barred olivine, radial pyroxene, and cryptocrystalline. Many chondrule mesostases retain a glassy and/or quenched texture, apparently unaffected by pre-terrestrial aqueous alteration (Fig. 2).

Most olivine grains show undulatory extinction and irregular fractures, though a few instances of planar fractures exist (Fig. 3). According to the shock classification scheme for ordinary chondrites (Stöffler et al., 1991), undulatory extinction in olivine is ubiquitous in chondrites of shock stage S2 (very weakly shocked), and planar fractures occur at stage S3 (weakly shocked).

The modal abundances of the chondritic components determined from the NWA 7402 thick section by point counting (Table 1) are consistent with those of ordinary chondrites (e.g., Brearley and Jones, 1998; Weisberg et al., 2006). No Ca–Al-rich inclusions were found in the sections studied, although one aluminous chondrule was identified. The fine-grained silicate rims that surround some chondrules are typically FeO-rich and embedded with micron-sized Fe sulfides. Large opaque assemblages (~300 μm in diameter) contain kamacite, taenite, Fe sulfides, and Fe oxides. The sulfides

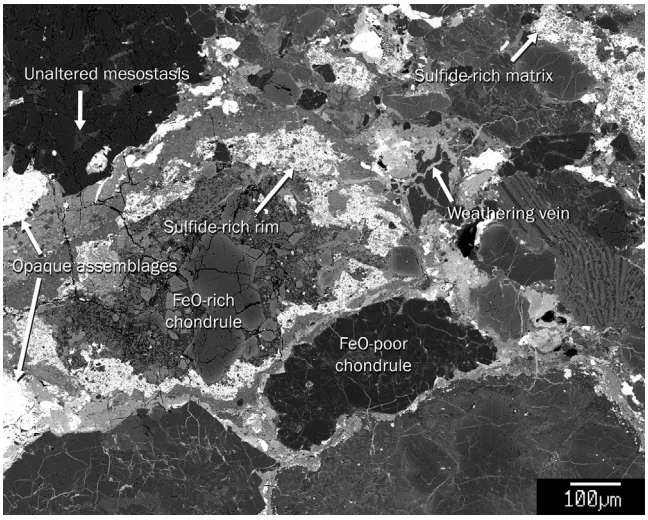

Fig. 2. BSE image of NWA 7402 showing a variety of chondrule types embedded in a fragmented matrix. Much of the fine-grained material is sulfide-rich, and multiple opaque assemblages are apparent.